PARAMETERS AND FILTERS FOR LOW BIT RATE WAVELET PACKET COMPRESSION OF MAGNETIC RESONANCE IMAGES

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Abstract- **We present an analysis of the characteristics of different filters for the compression of magnetic resonance images. Compression rates were 33:1 and 50:1. We compare the performance among different types of wavelets presented in the literature and provide quantitative (percentage of energy retained, peak signal to noise ratio) and qualitative (analysis by a group of seven experts) data to support our conclusions. Different types of coiflets, symlets and biorthogonal wavelets are analyzed, and we conclude that for the images under study (T1 weighed images in three planes), the best results are provided by the biorthogonal spline (Daubechies) wavelet 2,6. Several explanations for these results are mentioned.**

Keywords- **Image compression, wavelet packets, magnetic resonance imaging**

I. INTRODUCTION

In the last years the growth of digital imaging in the medical environment has outpaced any reasonable expectations. This growth has profited from the developments in computer and communications technology for storage and transmission of images within and among medical establishments. Even with growing bandwidth and diminishing costs, transmission and storage of medical images quickly runs into limitations. One of the approaches to these limits is to compress the images in order to reduce both storage space and transmission time. Although several image compression methods such as JPEG have been standardized for some time, these methods have not been widely accepted in the clinical environment. This is due to the fact that in order to achieve high compression rates, inexact or "lossy" algorithms such as the discrete cosine transform have to be employed, and these algorithms introduce distortions or artifacts that may affect the diagnostic quality of medical images.

The theory of wavelet analysis has proved to be a very important development in the search of more efficient methods of image compression. In particular, the fact that wavelet coefficients indicate changes in the signal under analysis means that areas of small changes or with no changes at all will produce small-valued coefficients. In the case of image compression, generally there are many areas of this type in a typical image so image compression using this scheme should be quite efficient.

Different properties of the wavelets have been studied under the point of view of efficient compression. In particular, the number of vanishing moments has been linked to signal-to-noise ratio and smoothness v.s. ringing in compressed image reconstruction. Other properties such as symmetry and regularity have also been evaluated in this light [1,2]. In addition to this, researchers in the field of vision as well as those dedicated to wavelet analysis [3,4] have proposed a link between the properties of the wavelets and the performance of the human visual system. The spatial response of the human visual system has been compared to a Gabor function, which has been linked to some wavelet filter banks. Because of this, he relationship between the amplitudes of the primary and secondary lobes of some wavelets has been studied in the analysis of the performance of different wavelets for image compression [5]. Other authors have analyzed quite a number of wavelet filter banks in order to determine those with the best characteristics for compression. In this respect, some of the most cited wavelets are Coiflets, which have the highest number of vanishing moments for a given support width; Symlets, which are nearly symmetrical, which means that they behave like linear phase filters, that are known to be important for image compression, and biorthogonal filters, which allow for perfect reconstruction without redundancy, and offer symmetry and compact support [6].

The purpose of this paper is to investigate which are some of the parameters that are directly responsible for the quality of low bit-rate coded images. Several filter banks that have been mentioned in the literature are evaluated, together with parameters such as filter length, symmetry and wavelet shape.

II. METHODOLOGY

For the purpose of this study, four types of image were analyzed: Three T1-weighed magnetic resonance slices in the axial, saggittal and coronal planes, and a common Lena image. Images were compressed at 33:1 and 50:1 ratios using the wavelet packet decomposition at five levels, and the Shannon entropy criterion for the selection of the best tree. The wavelet coefficients were thresholded in order to achieve the desired compression rate. Coefficients below the threshold were set to zero. Three groups of wavelets were employed in this study: Coiflets, Symlets and Biorthogonal. A preliminary study was carried out in order to select the best performing wavelets in each group. The wavelets that were retained were Symlets 6, 7 and 8; Coiflets 2,3, 4 and 5; Biorthogonal (Daubechies) 2,8, 3,9, 5,5, and 6,8.

Quantitative analysis consisted in the measurement of the peak- to-peak ratio, the peak signal to noise ratio and the percentage of the energy retained after compression for both compression rates, as well as the determination of the symmetry of the reconstruction filter Ψ.

Qualitative analysis was carried out by a group of seven experts on medical images from the Image Processing Laboratory at UAM-Iztapalapa and the National Institute of Neurology and Neurosurgery at Mexico City. Images were displayed on high-quality 17" flat displays set at 1024 x 768 pixel resolution at an 85Hz refresh rate. The experts graded the images on a 10-point scale, ranging from 0 (unusable images) to 10 (images deemed equal to or as good as originals).

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III. RESULTS

Table 1 shows the data for the quantitative analysis for the four images and all the filter types. The second column shows the values for the percentage of the energy retained after compression (expressed as the fraction of this value after 99%). The middle columns show the peak signal-to-noise ratio for the two compression ratios involved. The last two columns show the symmetry and the peak-to-peak ratios for all the wavelet types. Qualitative analysis data are shown on Figure 1. The mean values and the standard deviations are shown for all filter types.

image/wavelet	ENRet99.	PSNR97	PSNR98	symmetry	PPR
axis6	52	33.33	31.03	0.98	1.34
axis7	23	33.68	31.35	0.97	1.49
axis8	57	33.86	31.44	1	1.18
axic2	19	33.4	31.09	1	1.43
axic3	37	34.71	32.15	1	1.42
axic4	70	35.47	32.56	1	1.37
axic5	77	36.63	33.46	1	1.35
axib28	91	38.1	35.03	1	1.39
axib39	85	36.1	33.45	1	1.44
axib55	68	35.1	32.52	1	1.4
axib68	73	35.73	33.1	1	1.37
sas6	-1.9	15.57	15.64		
sas7	-1.97	15.57	15.66		
sas8	-1.7	15.56	15.63		
sac2	-1.97	30.21	28.55		
sac3	-1.45	31.31	29.39		
sac4	-1.3	31.95	29.77		
sac5	-1.02	32.68	30.23		
sabi28	29	15.45	15.48		
sabi39	60	15.46	15.5		
sabi55	-0.86	15.5	15.54		
sabi68	-1.15	15.53	15.59		
cors6	-1.22	34.42	32.33		
cors7	-1.06	34.85	32.69		
cors8	-1.04	34.94	32.7		
corc2	-1.09	34.68	32.6		
corc3	-0.93	35.31	32.94		
corc4	-0.58	36.5	33.82		
corc5	-0.63	36.64	33.69		
corbi28	53	39.74	36.85		
corbi39	72	38.26	35.53		
corbi55	-0.3	37.09	34.6		
corbi68	66	43.97	40.44		
lens6	-0.31	28.42	26.46		
lens7	-0.43	28.08	26.15		
lens8	-0.33	28.56	26.48		
lenbc2	-0.51	27.76	25.83		
lenbc3	-0.59	27.72	25.66		
lenbc4	-0.26	29.08	29.69		
lenbc5	-0.22	29.49	26.84		
lenb28	64	32.91	32.92		
lenb39	68	31.38	29.94		
lenb55	22	28.48	28.48		
lenb68	-0.21	26.74	26.74		

Table 1. Results of quantitative analysis.

Statistical analysis was carried out first, by analysis of variance, where the null hypothesis, Ho (all the means are equivalent) is rejected at the 95% confidence level. However, as the qualitative grading system is considered to be a "soft" variable, the condition of normality cannot be assumed, we carried out the Friedman test, which is well-suited for an evaluation where different judges evaluate several classes of objects. In this case Ho (grades are not correlated) is rejected, with a value of $P \leq 0.00000001$, Q=48.09. These results mean that the different processes can be distinguished among them.
The columns have different values (different processes) and the rows are correlated (there is agreement among grades). In addition to this study, the analysis of the modes of the grades together with the average values of the grades do allow us to determine which is the best type of filter for the images under study. Figure 2 shows the different reconstructions for the best filters of each of the different major types of wavelet. The compression ratio in this case is 50:1 in order to make errors more noticeable.

IV. DISCUSSION

For biorthogonal wavelets, b2.8 and b3.9 the percentage of the energy recovered from the 50:1 compressed images was in all instances over 99%, and this occurred only for these filters. Other filters with over 99% of the energy recovered were b5.5 for the Lena image and b5.5 and b6.8 for the axial MR images. It is worth noting that for the cases of filters b5.5 and b6.8, where decomposition and reconstruction filters are quite similar, results were acceptable, but were not the best. On the other hand, the best biorthogonal wavelets corresponded to the longest filters tested. At the high compression rates that were used, and with the wavelets that were tested, it appears that the number of vanishing moments and the evaluation of regularity are of secondary importance when compared to other attributes of the filter banks.

The type of images that were tested was selected purposely in order to test the wavelets under different situations. In the first instance, the axial MR images were selected in order to test the compression methods under the best of circumstances. Since most of the image information is in the center of the image, and the periphery is mostly dark, there should be no need to remove border artifacts, and the processing algorithms should be relatively free of artifacts, and indeed this is the case. The second type of image corresponds to the coronal slices, where again, most of the information is centered. The third type of image is a slice from a saggittal study, and here, since there is a larger

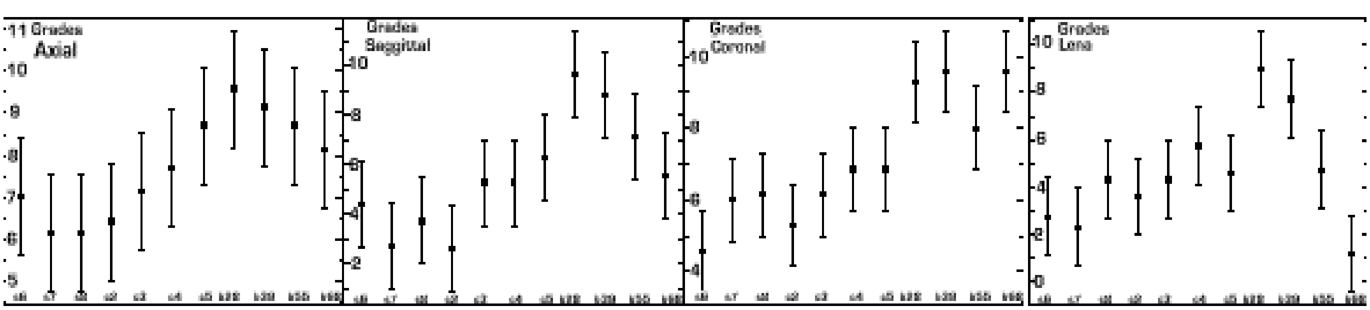

Figure 1. Average grades for the four images compressed with the wavelets under study.

amount of information near the edges, we expected results with more reconstruction artifacts. The final image is a standard 256 x 256 Lena, where no effort was made to avoid the edge artifacts.

Averaged results show that for the case of a 33:1 compression ratio, grades were over 9,5/10 for all the MR modalities, while the Lena image was graded with a 9/10. In all these instances the wavelet that presented the best results was b2.8, except for the case of saggittal images, where wavelet b3.9 got the best results. For a 50:1 compression ratio, results show the same pattern, with grades over 8.4 for all the modalities, with filters b2.8 giving the best results except on the saggittal images where filter b6.8 was deemed to be the best, filter b3.9 second best, and b2.8 third best. Results for modal analysis are very similar. At a 33:1 compression ratio, wavelet b2,8 is graded highest in all instances while wavelet 3,9 received the same grade in the case of axial and coronal images. Wavelet b6,8 was also assigned the highest grade in the case of coronal images. In the case of a 50:1 compression ratio, wavelet b2,8 got the highest grades in all cases except for the coronal images, where wavelets b6,8 and b3,9 received higher grades.

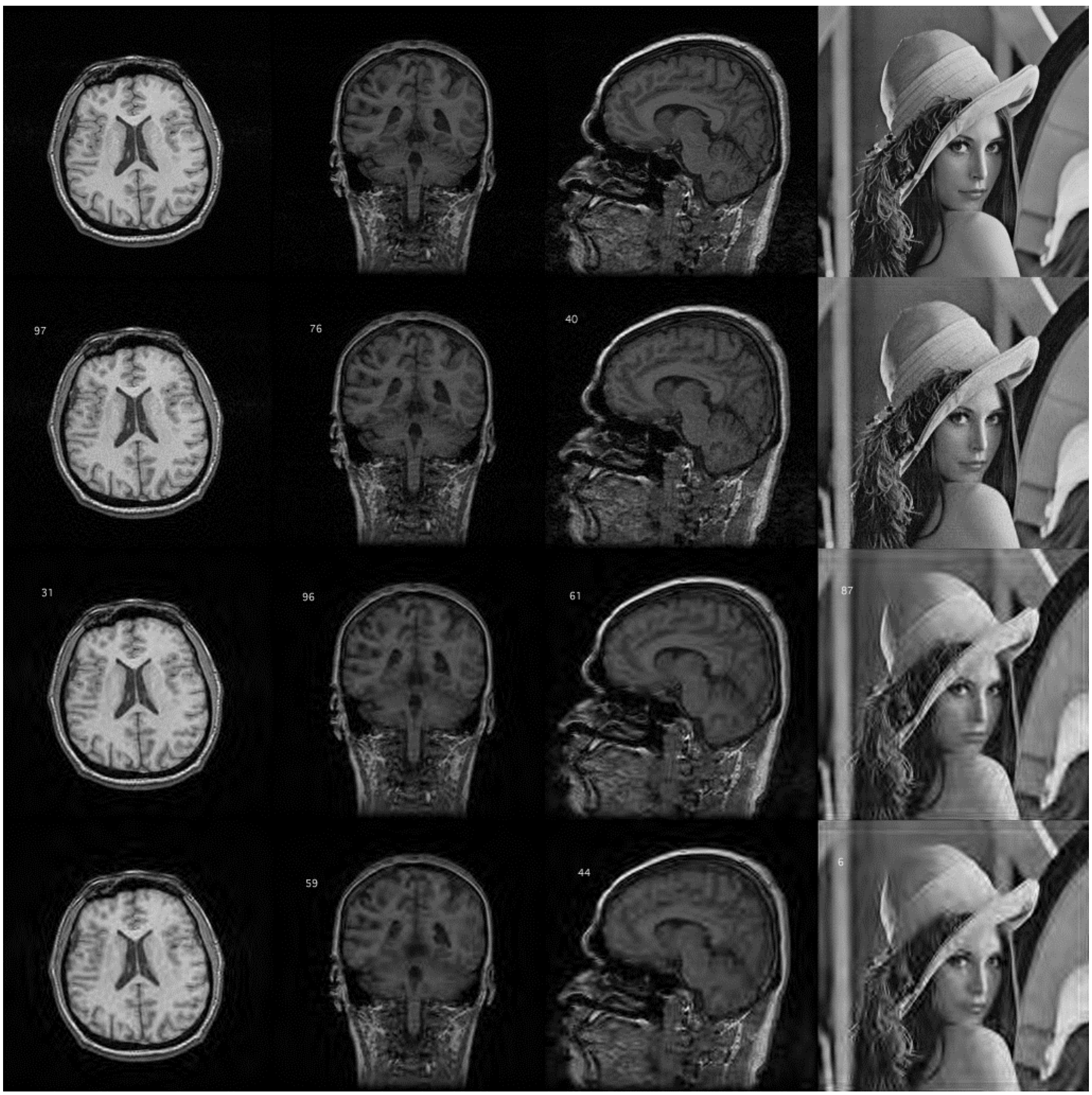

Figure 2. Results for a 50:1 compression rate and the best filters of their kind. Top row: original images; second row: biorthogonal 2,8; third row: coiflet C5; last row: symlet s8.

V. Conclusion

To summarize the results, we can say that among the different types of wavelets that were tested for compression at high rates, "symlets" were the least appropriate for compression of images in general. The "coiflets" that were tested in this study were similar in shape to most other wavelets in the study. It is possible that the degree of assymmetry in the filters, while small, does not allow an adequate reconstruction. In the case of the "coiflets" that were tested, the results were almost always inferior to those achieved by biorthogonal filter banks. In some instances filter C5 outperformed some of the biorthogonal filters, but was ranked at the most in 4th place among the filters that were tested.

The biorthogonal filter banks were the best performers in the group, particularly filters b2.8, b3.9 and in one instance, filter b6.8. A possible explanation for this performance might lie in the fact that these are the longest filters among those tested, which allows a better representation of details. These same filters obtain the best results for the qualitative evaluation, as well as for several quantitative indexes such as the Peak Signal to Noise Ratio and the percentage of the energy retained after compression, and are similar to those described in [7].

It appears that the gross wavelet shape as described by the peak to peak ratio can provide a general idea on the performance of the wavelets but is not a reliable index to performance in image coding at high compression rates. None of the indexes or measures that have been used can predict individually the quality of results, but taken as a group are generally consistent in the evaluation of results. It is possible that a combination of the peak-to-peak ratios with the percentage of the energy recovered can be constructed to form an index that might predict image quality after reconstruction in an adequate manner.

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